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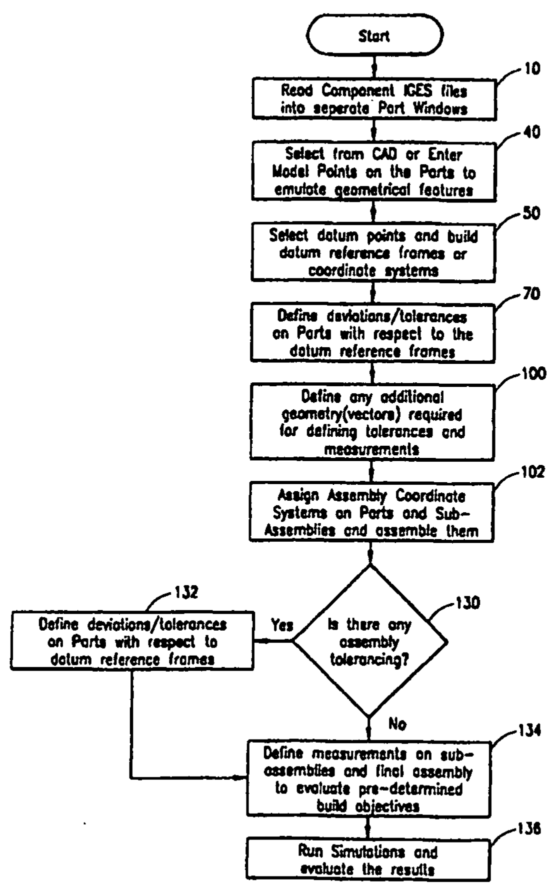
(54) Title: METHOD AND APPARATUS FOR MANUFACTURING DESIGN

(57) Abstract

A method and apparatus for modeling and analyzing components of a manufactured product. Software, running on a digital computer, models features and components, including predetermined build objectives, of a product and assembles the components based on their coordinate systems. The software allows the user to view multiple solutions of the assembly process. Additionally, the software analyzes the tolerances of the features to assist in determining which tolerances are not critical to the finished product and to what extent the tolerances may be increased to lower manufacturing costs.



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METHOD AND APPARATUS FOR MANUFACTURING DESIGN

BACKGROUND OF THE INVENTION

The present invention relates to software and, more particularly, to software for analyzing and optimizing the design of manufactured products.

Computer aided design ("CAD") software is well known in the art. This software allows a user to model components of a product on a computer and to designate positions of features, such as holes. Manufacturing tolerances, as set by the designers, may also be modeled by the software. Designers may modify the tolerances once they are entered into the software; however, CAD software is unable to suggest alternatives to the entered tolerances or alter the modeled product to allow the user to view the product with various tolerances.

Design analysis software allows a user to model components of a manufactured product, model features on the component, such as a hole, and designate tolerances for the feature, similarly to CAD software. Additionally, the software assembles the components into the manufactured product. To do so, the user designates points on each component, and the software matches the points to assemble the components. If the points can be matched in more than one fashion, the user typically receives an error message. The user may then designate additional points to further limit the degrees of freedom of the components so that they can be properly assembled by the software. Further, once the product is assembled, changes to the components cannot be made in real time. If a component is modified, the software must be instructed manually to update the product. If a product is assembled from two or more duplicate or symmetrical components, after one component is modeled, the remaining components may be duplicated or mirrored; however, the user must manually enter new variable names for each of the points and features, which may lead to tedious and repetitive work.

SUMMARY OF THE INVENTION

The aforementioned problems are overcome by the present invention wherein

software has the capability of modeling components, assembling the components based upon their coordinate systems, and providing analysis of the tolerances and the manufactured product.

In a first aspect, the software models components and features on the components and allows the user to enter design tolerances for the features. Duplicate or syrnmetrical components may be copied by the software, and it automatically assigns new variable names to the features and any points designated on the component. Additionally, the user may enter notes in a separate pop-up window for every point and tolerance designated.

In a second aspect, the software assembles the components based upon their coordinate systems. Each component has a defined coordinate system which the software matches to assemble the components. If there are multiple solutions of the assembly, the software steps through each station and allows the user to select the correct assembly.

In a third aspect, the software analyzes the tolerances defined for each feature. The software determines, for example, which feature tolerances may be increased to lower manufacturing costs. Additionally, the software generates "what if" reports whereby the tolerances may be increased to determine the overall effect for the manufactured product, and the user may review the spread of specification limitations through simulations.

The present invention resulted from the recognition that there is a need for more sophisticated analysis techniques for designing and manufacturing products. The present invention allows designers to determine which feature tolerances, if any, are as critical to the manufacturing of the product and which may be increased to lessen the manufacturing costs. Additionally, the software allows the designers to study the effect on the manufactured product of overall increases and decreases in the tolerances as a whole, for individual features or for individual components. Thus, the designer may more easily manager the tolerances and the associated manufacturing costs.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a flowchart of the method for analyzing and optimizing the manufactured product;

Fig. 2 is a sample screen showing the components entered in the software;

Fig. 3 is a representation of the components as modeled in the software;

Fig. 4 is a schematic showing the selection of points;

Fig. 5 is a sample screen showing the points selected on one component;

Fig. 6 is a schematic showing the use of sub-datuming in defining the coordinate systems;

Fig. 7 is a flowchart of the algorithm used for emulating tolerances;

Fig. 8 is a schematic illustrating pattern and feature tolerances;

Fig. 9 is a sample screen showing the assembly coordinate system defined;

Fig. 10 is a ample screen showing the Assembly Coordinate icon;

Fig. 11 is a sample screen showing the assembly of two components;

Fig. 12 is a sample screen showing two of the components assembled;

Fig. 13 are sample screens showing multiple solutions of the assembled components;

Fie. 14 is a sample three-box report providing analysis of the tolerances; and

Fig 15 is a sample four-box report providing analysis of the tolerances.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention includes software for use on a digital computer (not shown). The method encompassed by the software is illustrated in Fig. 1. Preferably, the software is a window-based application.

As a first step of the method illustrated in Fig. 1, the component information is read into data files to which the software has access 10. Preferably, the information for each component is stored individually so that it may be loaded and viewed graphically in separate windows within the software. The software reads data files formatted in the International Graphics Exchange Syntax ("IGES") and the Surface International Graphics System ("SIGS"), or it translates files from various proprietary CAD systems. Alternatively, the components may be modeled directly in the software.

Additionally, the components may be modeled using the "mirror" or "duplicate" functions. In the mirror function, used in conjunction with symmetrical components, one-half of the component may be modeled directly in the software or the data for one half of the component may be loaded from a CAD system, and the remainder of the component

is modeled by mirroring the previously modeled one-half about a vertical axis. In the duplicate function, used in connection with component comprised of multiple identical pieces, such as panels, one portion of the component may be modeled or loaded from a CAD system, and the portion is then duplicated as many times as necessary to form the remainder of the component.

As seen in Fig.2, a sample screen 20, commonly known as the assembly flow diagram 21, graphically shows three components, a fixture 22, block 2 24, and block 1 26, modeled in the software and represented on the screen 20 by icons 28, 30, and 32. The data for each of the components 22, 24, and 26 is stored individually. Double-clicking one of the icons 28, 30, or 32 opens a separate window for each of the components 22, 24, or 26 so that each may be manipulated individually. Representations 34, 36, and 38 of the components 22, 24, and 26, as modeled within the software, are seen in Fig. 3.

The second step of the method illustrated in Fig. 1 is to designate points 39 on the components to emulate features 40. As seen in Fig. 4, features 42, such as holes, protrusions, or a point on the surface of the component, are noted on each component 22, 24, or 26. Preferably, the user selects points 39 which were imported from a CAD system to emulate the features 42. However, the user may enter coordinates into the software to designate the points 39.

If the mirror or duplicate function is used when modeling the components, any points designated on the first portion of the component are copied during the mirror or duplicate function. However, the user has the option of adding a prefix and/or suffix to the name or other designation of each point to differentiate the mirrored or duplicated points from the original points.

The third step in the method illustrated in Fig. 1 is to form datum reference frames for each of the components 50. As seen in Fig. 5, the datum reference frame of a component is preferably defined by selecting at least three points on the component to limit the degrees of freedom of the component. For many components, up to six points may need to be selected to sufficiently limit the degrees of freedom. Thus, the datum reference frame is defined in relation to a global coordinate system; and the datum

reference frame provides a means for measuring the deviation of the features and the components relative to the datum reference frame, thereby allowing each component to have its own reference frame yet providing means for the deviations on individual components to be measured against each other based upon the global coordinate system.

To define the datum reference frame, the user may select points 52 on the component 54 which were imported from the CAD system, or the user may enter coordinates to select each point 52. Preferably, the points 52 selected emulate features on the component 54, such as holes, protrusions, or a surface of the component 54, and the points 52 selected are preferably those for which analysis is needed. For example, if a user wished to analyze the amount of space between two panel components of an assembly, the user would select at least one point on the surface of each of the panel components.

Fig.6 illustrates the relationship among a coordinate system 56, a datum reference frame 58, and a point, namely point "P" 60. As seen in Fig. 5(a), a first coordinate system 56 is defined; a second coordinate system 62 is defined, and point P 60 is defined in relation to the second coordinate system 62. As seen in Fig. 5(b), the second coordinate system 62, including point P 60, is deviated with respect to the first coordinate system 56 to form the datum reference frame 64 and point P' 66. Then, as seen in Fig. 5(c), the point P' 66 is allowed to deviate with respect to the datum reference frame 64 to form point P" 68. Thus, the deviation of the point P" 68 is defined in relation to the datum reference frame 64, and the datum reference frame 64 is defined in relation to the first coordinate system 56.

The fourth step in the method illustrated in Fig. I involves defining the tolerances of the components and features with respect to the datum reference frames 70. As seen in Fig.7, there are several steps involved in defining the tolerances on the features and components. First, the feature preferably is defined by a location and size, such as defining a hole having a diameter 72. Second, as seen in Fig. 8(a), the pattern and feature tolerances 76 and 78 must be determined 75. Typically, these tolerances are pre-defined by the designer of the component and are commonly known as pre-determined build objectives. Pre-defined tolerances are typically provided as follows:

⊗	σ .025M	A	B
	σ .006M	A	

where the pattern tolerance 76 equals .025 millimeters, and the feature tolerance 78 equals .006 millimeters. Additionally, the pattern is limited by two degrees of freedom as evidenced by the two points A and B 80 and 82 so that only translation of the pattern is allowed. The feature, limited in only one degree of freedom as evidenced by the single point A 84, may translate and rotate. The pattern includes at least two points or features on the component which the designer determines must move with respect to one another for the components to be properly assembled.

Third, a pattern deviation is determined using the two tolerances 76 and 78 defined by the pre-determined build objectives 80. Therefore, the root sum square calculation determines the deviation of the pattern based upon the pre-defined tolerances. For the above: referenced build objectives, the pattern deviation is calculated as follows:

$$\sigma_{\text{pattern}} = [(.025/6)^2 - (.006/6)^2]^{1/2}$$

Fourth, one of the points in the pattern is selected at random and preferably designated as A 82. Fifth, the pre-determined build objectives are reviewed to determine if the pattern is allowed to rotate 84.

If rotation of the pattern is allowed, the other points defined in the pattern are measured from point A to determine which point, designated B, is the furthest from point A 85. Next, both points A and B are deviated by the pattern deviation to deviate the points by a distance and an angle 86. The pattern deviation defines circular zones 87 (as seen in Fig. 8) within which points A and B may fall. The change in angle between point A and point B is determined by moving each of them the maximum distance allowable within the circular zone and calculating the change in angle between them. Thus, a maximum angle by which the pattern may rotate is determined. Next, a new orientation 88 of the pattern is determined 89. The translation of the pattern is based upon point A, and the rotation of the pattern is based upon the change in angle between points A and B.

If the pattern is not allowed to rotate, the pattern deviation is applied to point A

90. Again, as above, the pattern deviation defines a circular zone 87 within which point A must fall. Next, a new orientation 88 of the pattern is determined from the translation of point A 92.

Once the orientation 88 of the pattern is determined whether or not the pattern was allowed to rotate, each point in the pattern is transformed into a new position 94 based upon the orientation 88 96. Then, the standard deviation of the feature is calculated to determine to what extent the feature may deviate within the pattern 98.

Thus, the tolerances of the features are defined with respect to the pattern, also known as the datum reference frame, rather than to the global coordinate system.

The fifth step in the method illustrated in Fig. 1 includes defining any additional geometry required to define the tolerances 76 and 78 100. For certain components, geometry, such as vectors, may be needed to further define the tolerances 76 and 78 of the features. For example, a point on a surface of a component may be able to deviate in three dimensions due to gaps between components once they are assembled.

The sixth step in the method illustrated in Fig. 1 includes assigning assembly coordinate systems to the components and assembling them 102. The components are mated within the software based upon their assembly coordinate systems, rather than by matching points on the components. Therefore, an assembly coordinate system must be defined for each component.

The user may select the datum reference frame, which was previously defined, as the assembly coordinate system, or, as seen in Fig. 9, the user may select a new set of points 110 to limit the degrees of freedom of the component 54 and define a new coordinate system 112. However, in whichever manner the assembly coordinate system 113 is defined on each of the components 54, the points 110 used in defining the assembly coordinate system 113 must be selected in the same order on each of the components 54 to be assembled. For example, if two rectangular blocks are to be joined and a corner point is selected on the first block, the corner on the second block which will meet the corner point on the first block must be selected as a point. Additionally, the points 110 on each of the components 54 must be selected in the same order when defining the assembly coordinate system for each component. As seen in Fig. 10, the user clicks a

single button 114 on the screen to define the assembly coordinate system 113.

As seen in Fig. 11, once an assembly coordinate system is defined for each component, the first component 22, or fixture 120, is selected within the assembly flow diagram 21. The fixture 120 is defined as the component upon which the remaining components will be assembled. A second component 26 is also selected within the assembly flow diagram 21. The user selects from the software menu to "assemble the [selected component] on to the [selected fixture]" 122. The software, using the two defined assembly coordinate systems, mates the selected component 26 to the fixture 120 to form a subassembly 124. This relationship is seen graphically within the assembly flow diagram 21, as seen in Fig. 12.

As seen in Fig. 13, in some instances, there may be multiple solutions 126, 128, 130, and 132 to the assembly of the components 120 and 26. If so, the user is notified that multiple solutions 126, 128, 130, and 132 to the assembly exist, and the user is allowed to cycle through each of the solutions 126, 128, 130, and 132. The user may then select the solution 126, 128, 130, or 132 which visually appears correct.

Once the components 120 and 26 are assembled, real-time modifications may be made to the assembly 124 by opening the component windows and making modifications to the components 120 or 26. Any changes are saved in the component data and simultaneously in the assembly data, and any modifications made will appear graphically on the completed assembly 124.

The seventh step in the method illustrated in Fig. 1 includes determining if there are any tolerances defined for the assembly 130, similarly to the pre-determined build objectives defined for the features and patterns. Any assembly tolerances would be pre-defined by the designer of the assembly. If there is assembly tolerancing, then the deviations on the components are defined with respect to the datum reference frames 132, in the same fashion as the feature tolerances were previously defined with respect to the datum reference frames.

Whether or not any tolerances are defined for the assembly, the next step in the method illustrated in Fig. 1 is to define the measurements on any sub-assemblies and the completed assembly 134. Once the components are mated or assembled, the distance

between the corresponding points is calculated to determine the gap between the points. A designer of a component or assembly may define a maximum allowance between components as additional pre-determined build objectives to ensure an assembly that is comprised of tightly mated components and which does not have unsightly gaps or seams. The user may measure the gaps between selected points on the completed assembly and manually compare these results to the pre-determined build objectives.

The final step in the method illustrated in Fig. 1 is to run simulations on the components and assembly and evaluate the results 136. Figs. 14 and 15 show three and four element reports 150 and 152, respectively, which are available to analyze the simulation results. Preferably, a large number (at least 1000) of simulations are run, with the tolerances on each of the features being varied and then the components assembled. As seen on the left side of Fig. 14 and the lower left side of Fig. 15, the criticality of each of the feature tolerances on the components may be calculated 154. This allows the designer to determine which tolerances are the most critical to having the assembly meet the pre-determined build objectives and which tolerances are less critical, thus allowing the designer to increase tolerances for specific components to lower manufacturing costs. Additionally, the designer may examine the percent of parts that are out of the specification for a given measurement.

Further, the simulations may be run to generate "what if" reports 156. All tolerances on the features are increased by the same amount, which may be selected by the designer, and the simulations are run. The software plots, as seen in the lower right corners of Figs. 14 and 15, the percent of the components that have fallen outside of the pre-determined build objectives. The Process Capability Index ("C_{pk}") is calculated from the plot to evaluate the spread of the specification limits. The designer may run multiple simulations having multiple tolerance values to evaluate the feasibility of increasing the tolerances on the components to lessen manufacturing costs.

The above descriptions are those of preferred embodiments of the invention. Various alterations and changes can be made without departing from the spirit and broader aspects of the invention as defined in the appended claims, which are to be interpreted in accordance with the principles of patent law including the Doctrine of Equivalents.

WHAT IS CLAIMED IS:

1. A method for assembling components in a multi-dimensional model, comprising the steps of:

modeling at least two components of an assembly;

selecting at least three points on each component;

defining a coordinate system for each component based on said points; and

assembling said components by aligning said coordinate systems.

2. The method as recited in claim 1, wherein said assembling step comprises the steps of:

creating a plurality of multiple solutions by assembling said components in a plurality of configurations;

viewing said plurality of multiple solutions of said assembled components; and

selecting one of said multiple solutions as said assembly.

3. The method as recited in claim 1 wherein said modeling step includes entering data to create a representation of each of said components.

4. The method as recited in claim 1, wherein said defining step further includes defining a vector normal to said points.

5. The method as recited in claim 1, wherein said defining step includes defining tolerances on said components.

6. The method as recited in claim 5, wherein said tolerances are defined with respect to said coordinate system.

7. The method as recited in claim 5, wherein said tolerances are defined by determining deviations according to the steps of:

defining at least one feature on one of said components;

defining at least one tolerance for each of said features;

calculating a deviation for each of said tolerances;

selecting a point on said component at random;

determining an orientation of said component based upon said randomly selected point; and

transforming all points of said component into a new position based on said deviation.

8. The method as recited in claim 7, further comprising the step of:

applying respective deviations on all of said points on said component.

9. The method as recited in claim 7 wherein said determining step includes the steps of:

applying a position deviation on a first point; and

determining a new orientation of said component based on said first point.

10. The method as recited in claim 7, wherein said determining step includes the steps of:

calculating a distance between a first point and a plurality of additional points;

designating a given one of said additional points as a second point, said second point being the furthest distance from said first point;

applying a position deviation on said first and second points; and

determining a translation and rotation of said component.

11. A method of assembling components in a multi-dimensional model, comprising the steps of:

forming representations of said components;

storing each of said representations in a memory;

selecting at least three points on each component, said three points designating limits upon the degrees of freedom of said component; and

aligning said components based upon the respective degrees of freedom to assemble said components.

12. The method as recited in claim 11, wherein said aligning step comprises the steps of:

creating a plurality of multiple solutions by assembling said components in a plurality of configurations;

viewing said plurality of multiple solutions of said assembled components; and

selecting one of said multiple solutions.

13. The method as recited in claim 11, wherein said forming step includes entering data to create said representations of said components.

14. An apparatus for assembling representations of components in a multi-dimensional model, comprising:

modeling means for modeling at least two components of an assembly to form representations of said components;

selecting means for selecting at least three points in each of said representations;

defining means for defining a coordinate system for each representation based on said points; and

assembling means for assembling said representations by aligning said coordinate systems.

15. The apparatus as recited in claim 14, wherein said assembling means comprises:

creating means for creating a plurality of multiple solutions by assembling said representations in a plurality of configurations;

viewing means for viewing said plurality of multiple solutions of said assembled representations; and

selecting means for selecting one of said multiple solutions as a representation of said assembly.

16. The apparatus as recited in claim 14, wherein said modeling means includes display means for displaying each of said components in an individual window.

17. The apparatus as recited in claim 14, wherein said modeling means includes reading means for reading IGES files for each of said components.

18. The apparatus as recited in claim 14, wherein said modeling means includes data means for entering data to create said representations.

19. The apparatus as recited in claim 14, wherein sais defining means includes vector means for defining a vector normal to said points.

20. The apparatus as recited in claim 14, wherein said defining means includes tolerance means for defining tolerances associated with said components in said representations.

21. The apparatus as recited in claim 20, wherein said tolerances are defined with respect to the respective coordinate systems.

22. A method of emulating a tolerance in a multi-dimensional model of an assembly of a plurality of components, said method comprising the steps of:

defining a feature and a pattern on said model of one of said components, said feature including a location and a dimension;

determining an allowable tolerance for said feature;

calculating a standard deviation for said feature tolerance and for a pattern tolerance;

selecting, at random, a point on said pattern;

applying a position deviation on said randomly selected point;

determining an orientation of said pattern based upon said randomly selected point;

transforming a plurality of other points for said pattern to a new location based upon said orientation of said pattern; and

applying said position deviation on said plurality of other points.

23. The method as recited in clam 22, wherein, if said pattern is allowed to rotate, further comprising the steps of:

after the step of selecting said randomly selected point, determining which one of said plurality of other points of said pattern is the furthest distance from said randomly selected point;

said first applying step including said position deviation on said furthest distant point; and

said third determining step including determining a translation and rotation of said pattern.

24. A method of emulating a tolerance in a multi-dimensional model of an assembly of a plurality of components, said method comprising the steps of:

defining at least one feature on one of said components;

defining at least one tolerance for each of said features;

calculating a deviation for each of said tolerances;

selecting a point on said component at random;

determining an orientation of said component based upon said randomly

selected point; and

transforming a plurality of points on said component into a new position based on a respective deviation.

25. The method as recited in claim 24, further comprising the step of:

applying said respective deviation on all of said plurality of points on said component.

26. The method as recited in claim 24, wherein said at lease one feature is defined by a location and a size.

27. The method as recited in claim 24, wherein said respective deviation is calculated by the root sum square of two deviations.

28. The method as recited in claim 24, wherein said determining step includes the steps of:

applying a position deviation on a first point; and

determining a new orientation of the component based on said first point.

29. The method as recited on claim 24, wherein said determining step includes the steps of:

calculating a distance between a first point and a plurality of additional points;

designating a given one of said additional points as a second point, said second point being the furthest distance from said first point;

applying a position deviation on said first and second points; and

determining a new translation and rotation of said component.

30. A method of emulating a tolerance in a multi-dimensional model of an assembly of a plurality of components, said method comprising the steps of:

modeling a representation of each of said plurality of components, said representation including respective features and patterns of said components;

selecting a plurality of points on said representation of said component;

defining tolerances for a given pattern and a given feature;

determining a standard deviation of said given pattern; and

applying said deviation to said pattern.

31. The method as recited in claim 30, wherein said applying step includes the steps of:

selecting, at random, one of said plurality of points;

determining a distance between said randomly selected point and each of the other points of said plurality of points;

selecting one of other points having the greatest distance from said randomly selected point;

applying a position deviation on said randomly selected point and on the one other point; and

transforming each of said plurality of points into a new position.

32. The method as recited in claim 30, wherein said applying step includes the steps of:

selecting, at random, one of said plurality of points;

applying a position deviation on said randomly selected point;

determining a translation of said given pattern based on said randomly selected point; and

transforming each of said plurality of points into a new position.

33. A method of displaying a report on a number of tolerances associated with at least one component of an assembly, such method comprising the steps of:

generating a plurality of statistical data for a given simulation for said at least one component;

generating a plurality of tolerance criticality data for said given simulation;

generating a plurality of tolerance failure data for said given simulation;

displaying said plurality of statistical data, said plurality of tolerance criticality data and said plurality of tolerance failure data for said given simulation within respective discrete portions of said report.

34. The method as recited in claim 33, wherein said step of displaying said plurality of tolerance criticality data comprises the step of:

displaying a bar chart of said tolerance criticality data.

35. The method as recited in claim 34, wherein said bar chart comprises a three-dimensional bar chart illustrating said tolerance criticality data.

36. The method as recited in claim 33, further comprising the step of:

calculating, from said plurality of tolerance failure data for said given simulation, a process capability index associated therewith.

37. The method as recited in claim 33, wherein said respective discrete portions of said report are displayed together on a viewing screen.

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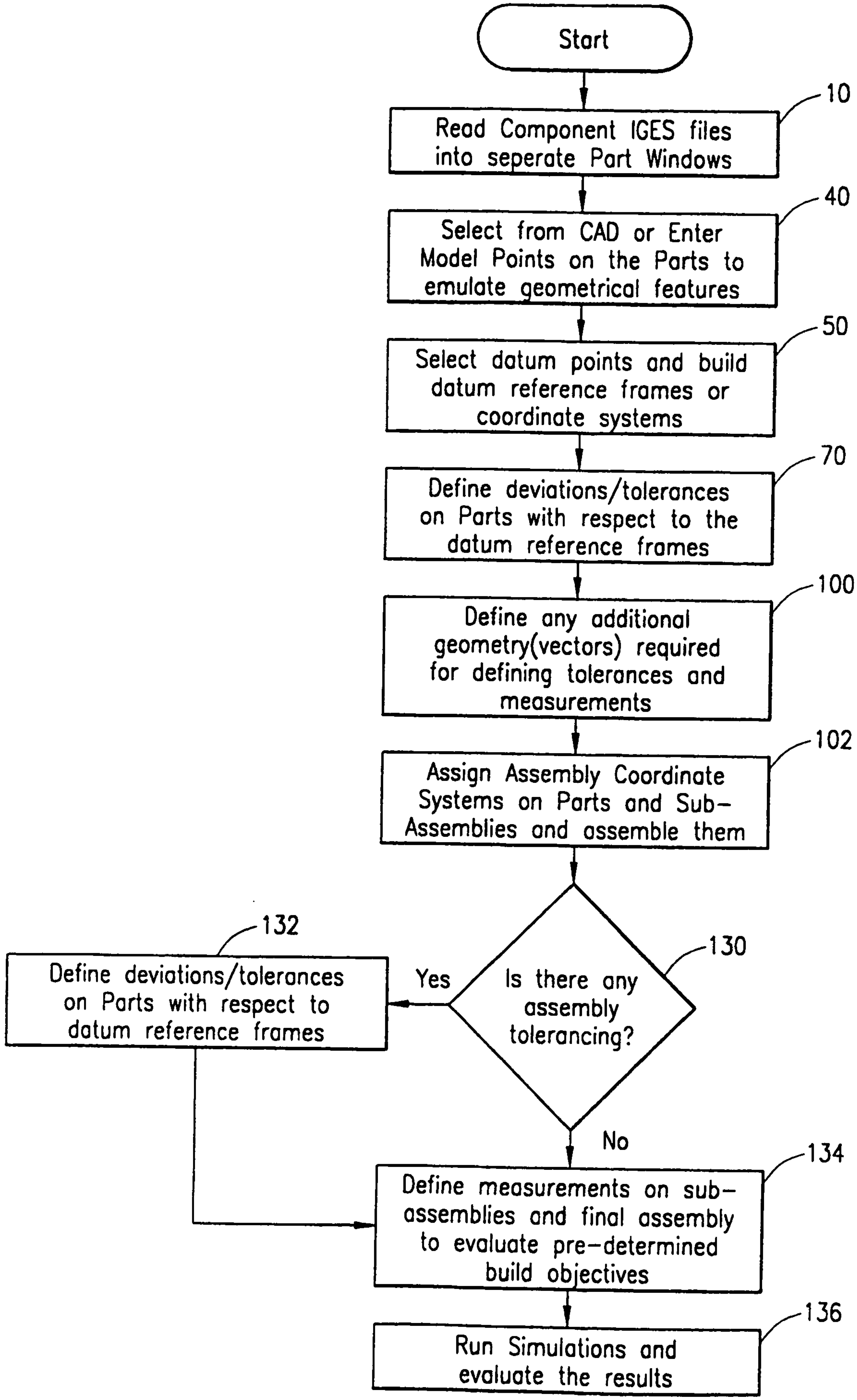

Start
Read Component IGES files into seperate Part Windows
10
Select from CAD or Enter Model Points on the Parts to emulate geometrical features
40
Select datum points and build datum reference frames or coordinate systems
50
Define deviations/tolerances on Parts with respect to the datum reference frames
70
Define any additional geometry(vectors) required for defining tolerances and measurements
100
Assign Assembly Coordinate Systems on Parts and Sub-Assemblies and assemble them
102
Is there any assembly tolerancing?
130
Yes
Define deviations/tolerances on Parts with respect to datum reference frames
132
No
Define measurements on sub-assemblies and final assembly to evaluate pre-determined build objectives
134
Run Simulations and evaluate the results
136

FIG. 1

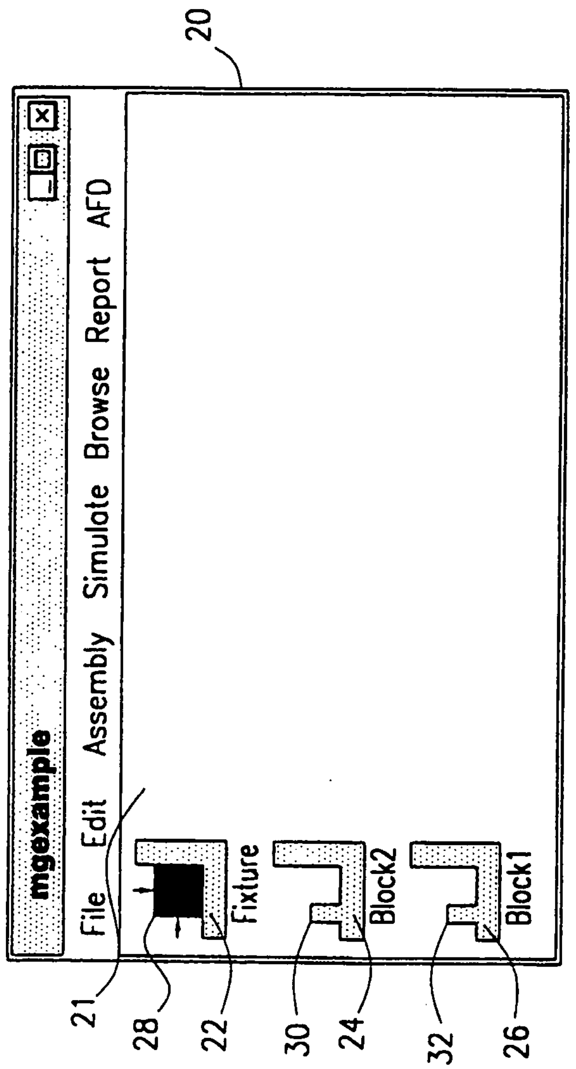

20
mgexample
File
Edit
Assembly
Simulate
Browse
Report
AFD
Fixture
Block2
Block1
21
28
22
30
24
32
26

FIG. 2

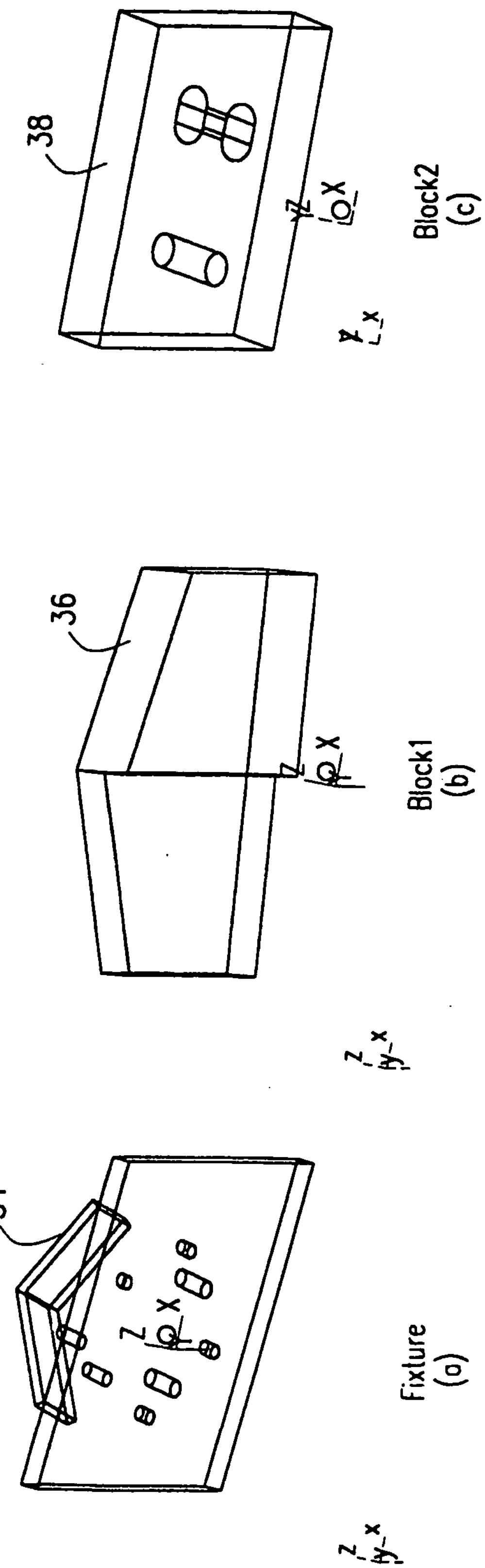

34
Fixture
(a)
36
Block1
(b)
38
Block2
(c)

FIG. 3

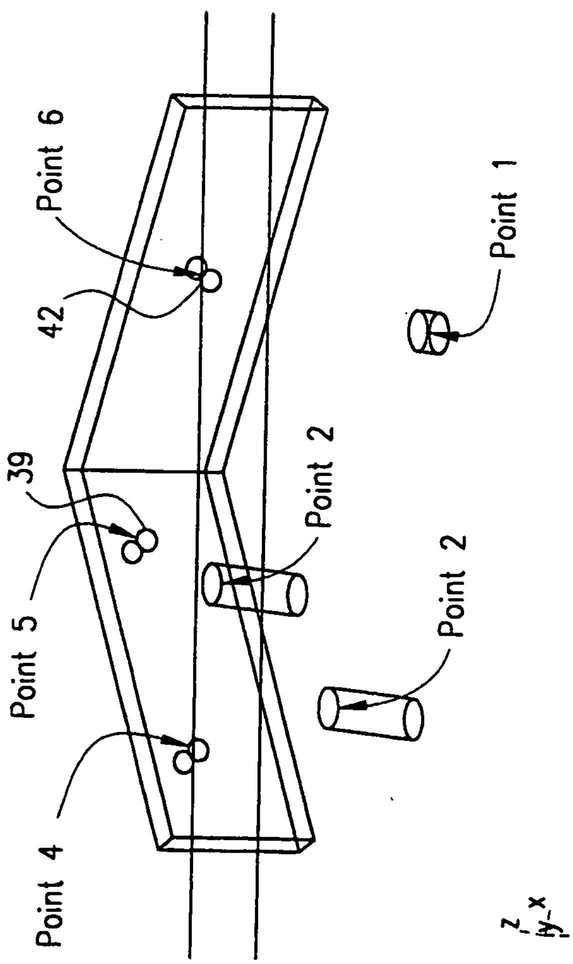


FIG. 4

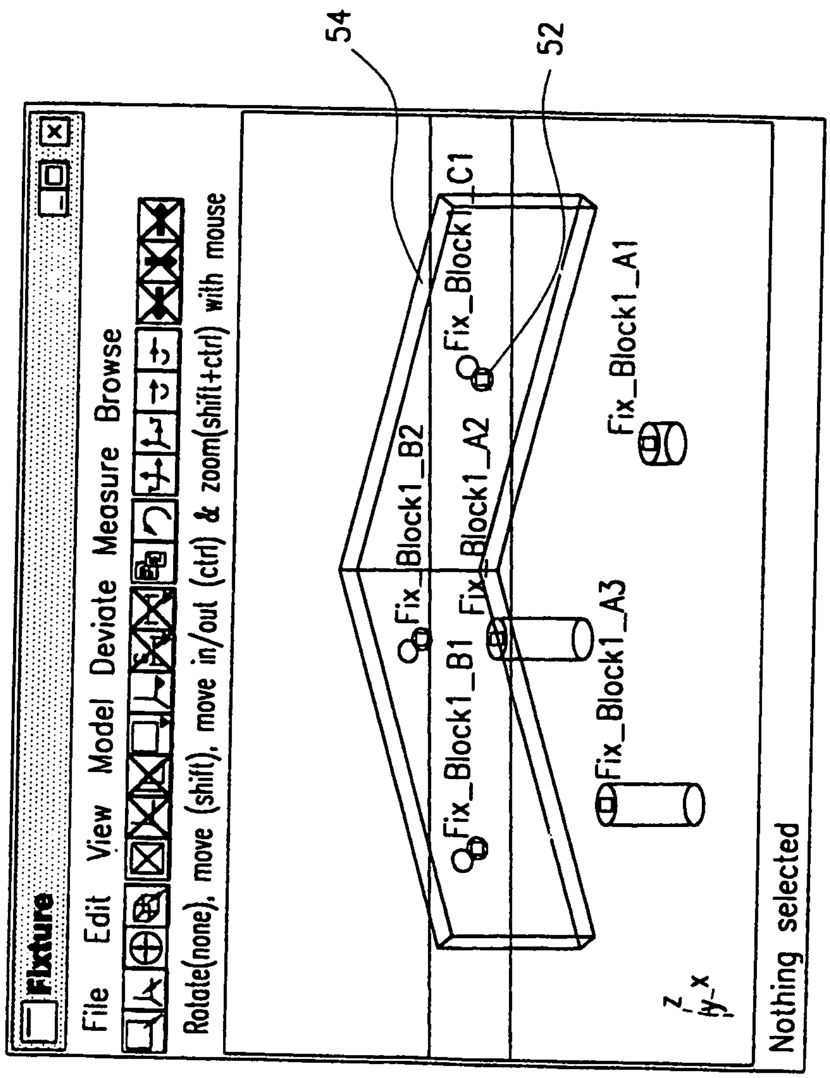
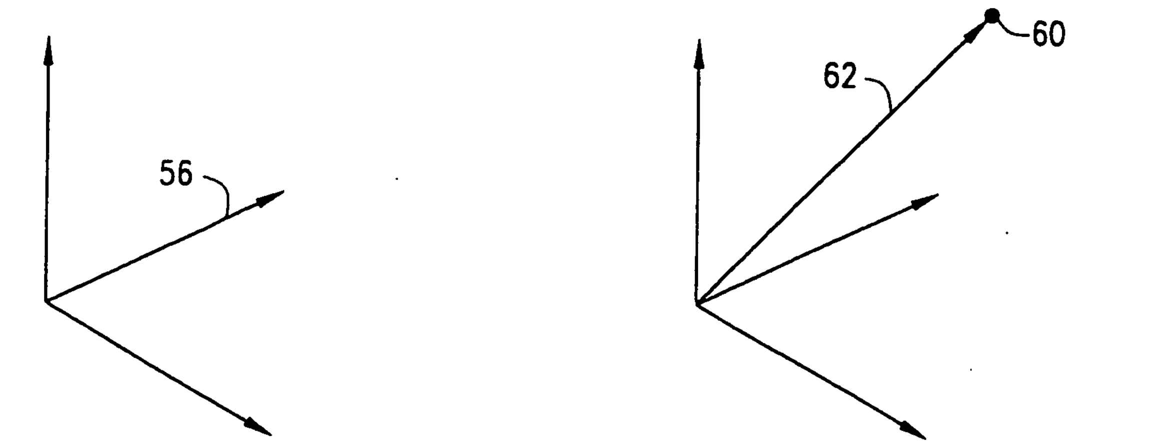
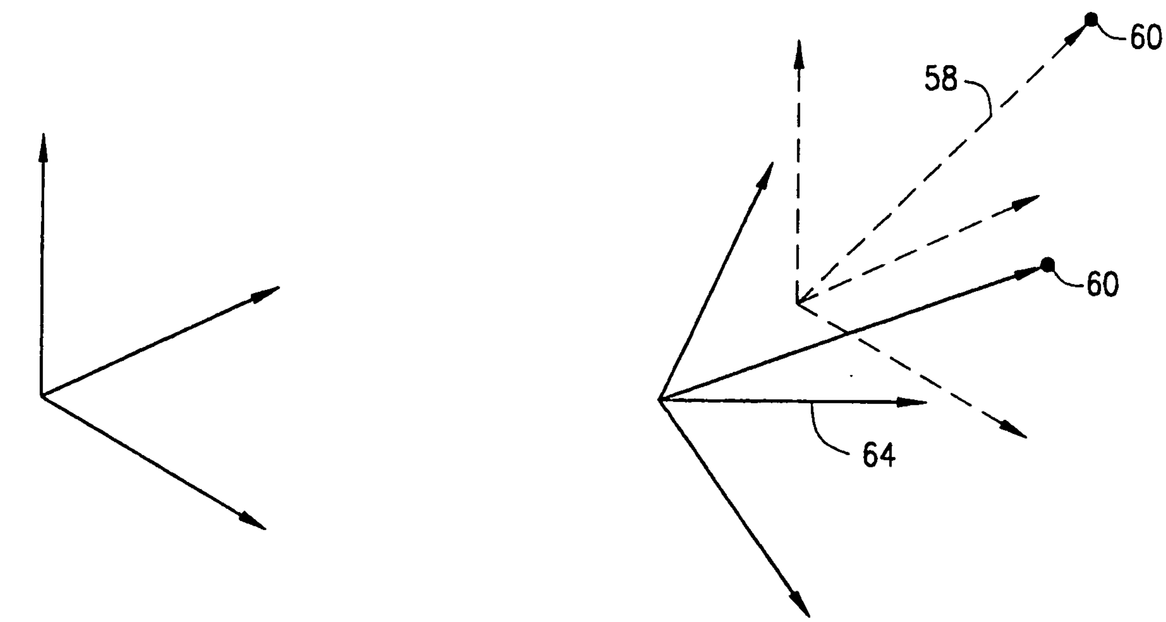

54
52
Fixture
File Edit View Model Deviate Measure Browse
Rotate(none), move (shift), move in/out (ctrl) & zoom(shift+ctrl) with mouse
Fix_Block1_C1
Fix_Block1_B2
Fix_Block1_A1
Fix_Block1_A2
Fix_Block1_B1
Fix_Block1_A3
Fix_Block1_C2
Nothing selected

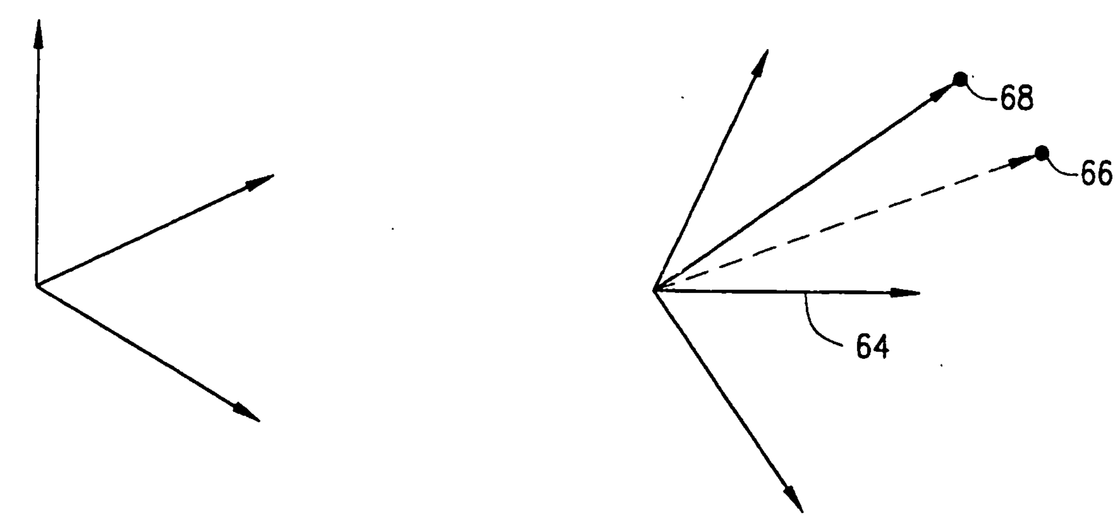
FIG. 5



(a)



(b)



(c)

FIG. 6

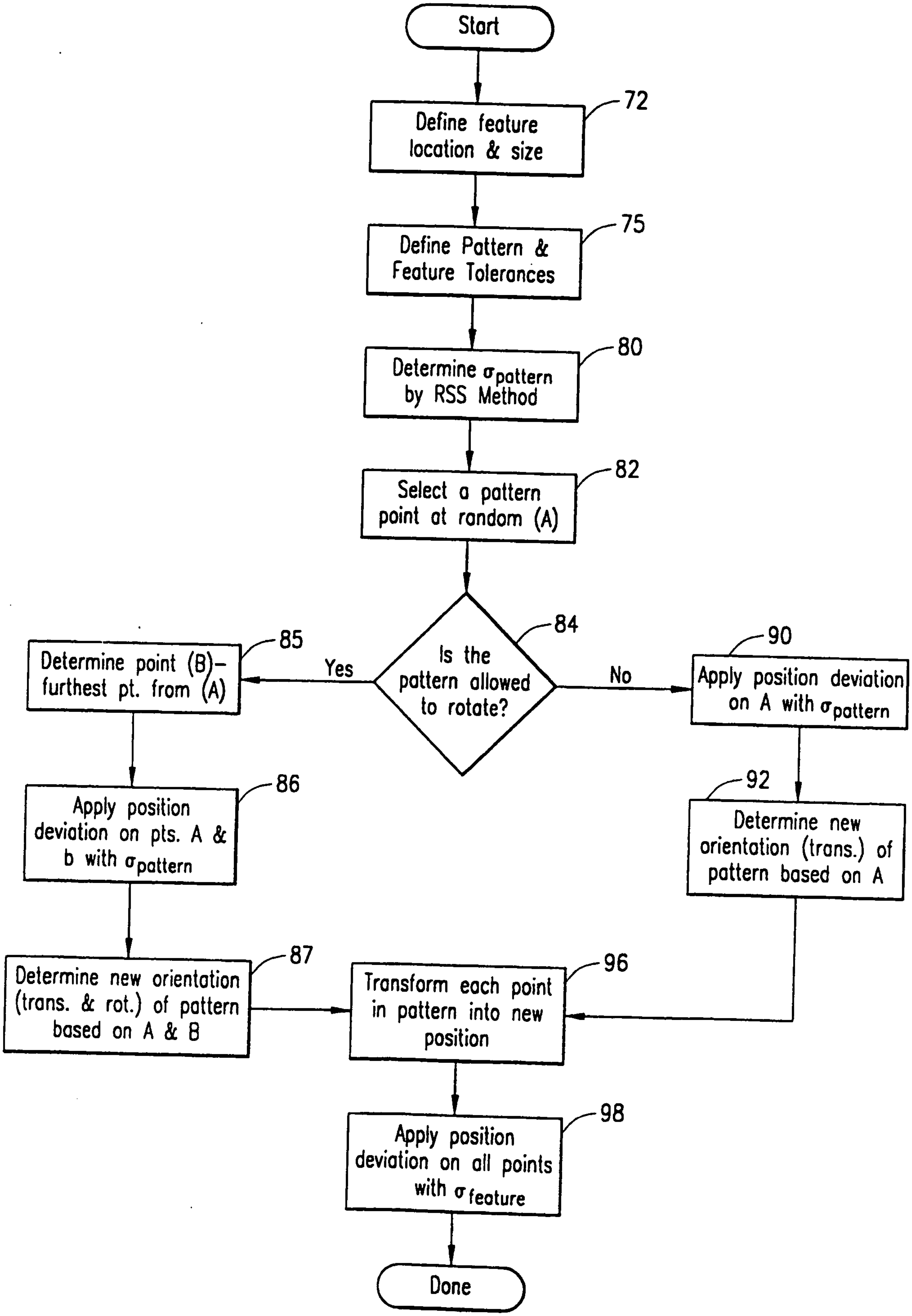

Start
Define feature location & size
72
Define Pattern & Feature Tolerances
75
Determine σpattern by RSS Method
80
Select a pattern point at random (A)
82
Is the pattern allowed to rotate?
84
Yes
No
Determine point (B)–furthest pt. from (A)
85
Apply position deviation on pts. A & b with σpattern
86
Determine new orientation (trans. & rot.) of pattern based on A & B
87
Apply position deviation on A with σpattern
90
Determine new orientation (trans.) of pattern based on A
92
Transform each point in pattern into new position
96
Apply position deviation on all points with σfeature
98
Done

FIG. 7

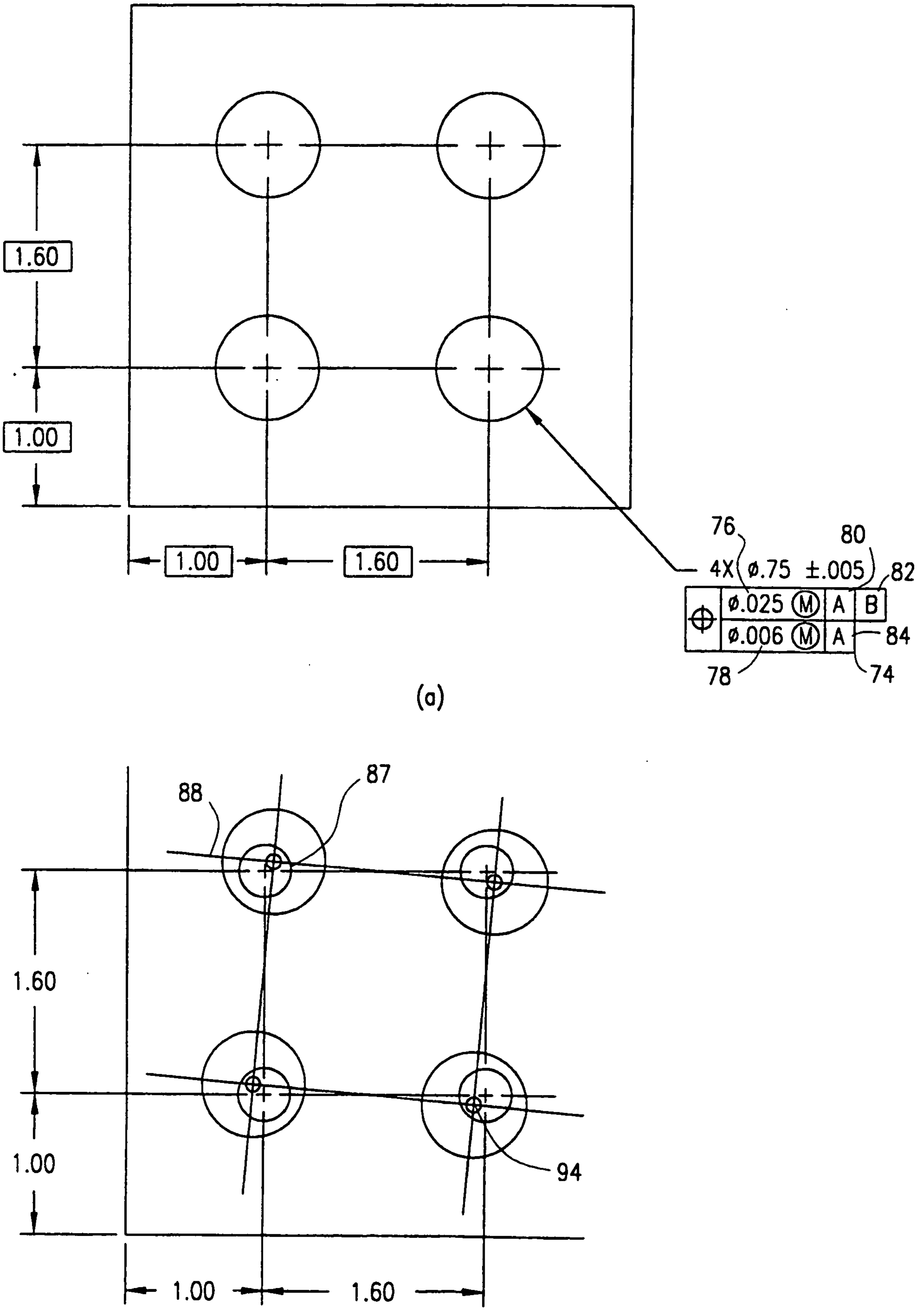

1.60
1.00
1.00
1.60
76
80
82
4X ø.75 ±.005
ø.025 Ⓜ A B
ø.006 Ⓜ A
84
78
74
(a)
88
87
1.60
1.00
94
1.00
1.60
(b)

FIG. 8

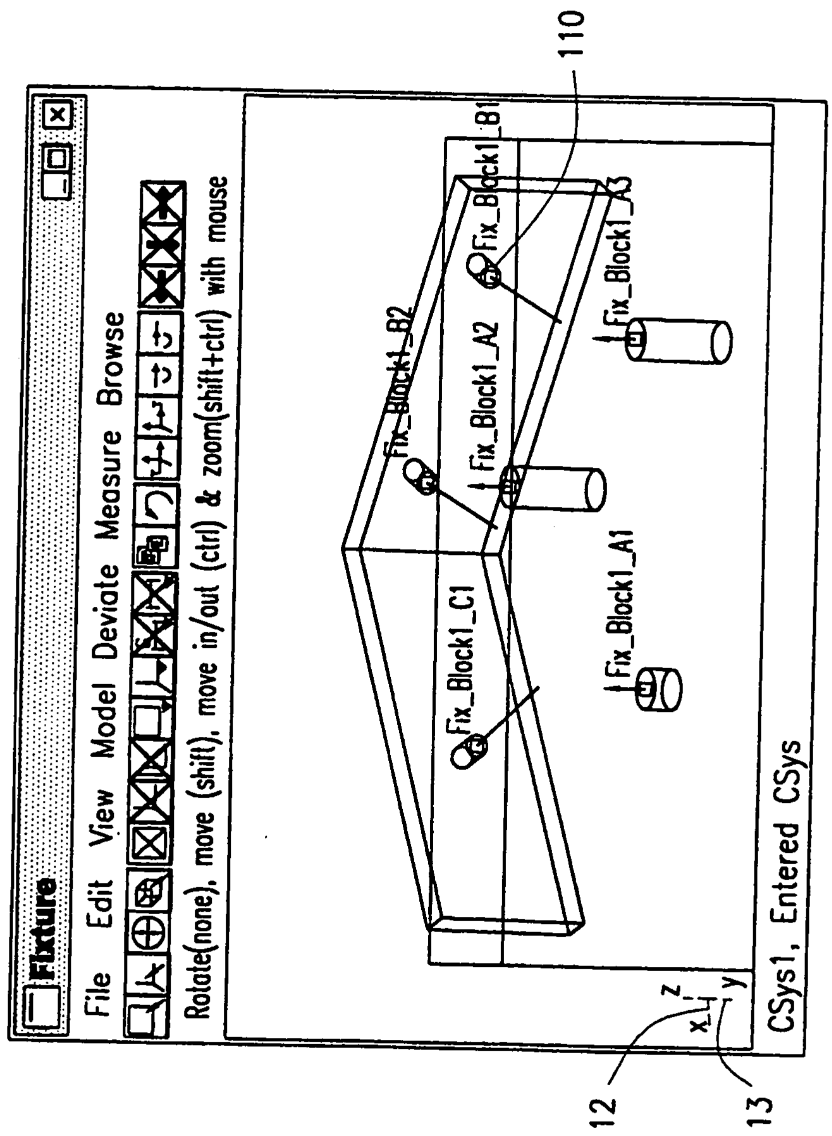

Fixture
File Edit View Model Deviate Measure Browse
Rotate(none), move (shift), move in/out (ctrl) & zoom(shift+ctrl) with mouse
Fix_Block1_B1
Fix_Block1_A3
Fix_Block1_B2
Fix_Block1_A2
Fix_Block1_C1
Fix_Block1_A1
z
x
y
CSys1, Entered CSys
110
112
113

FIG. 9

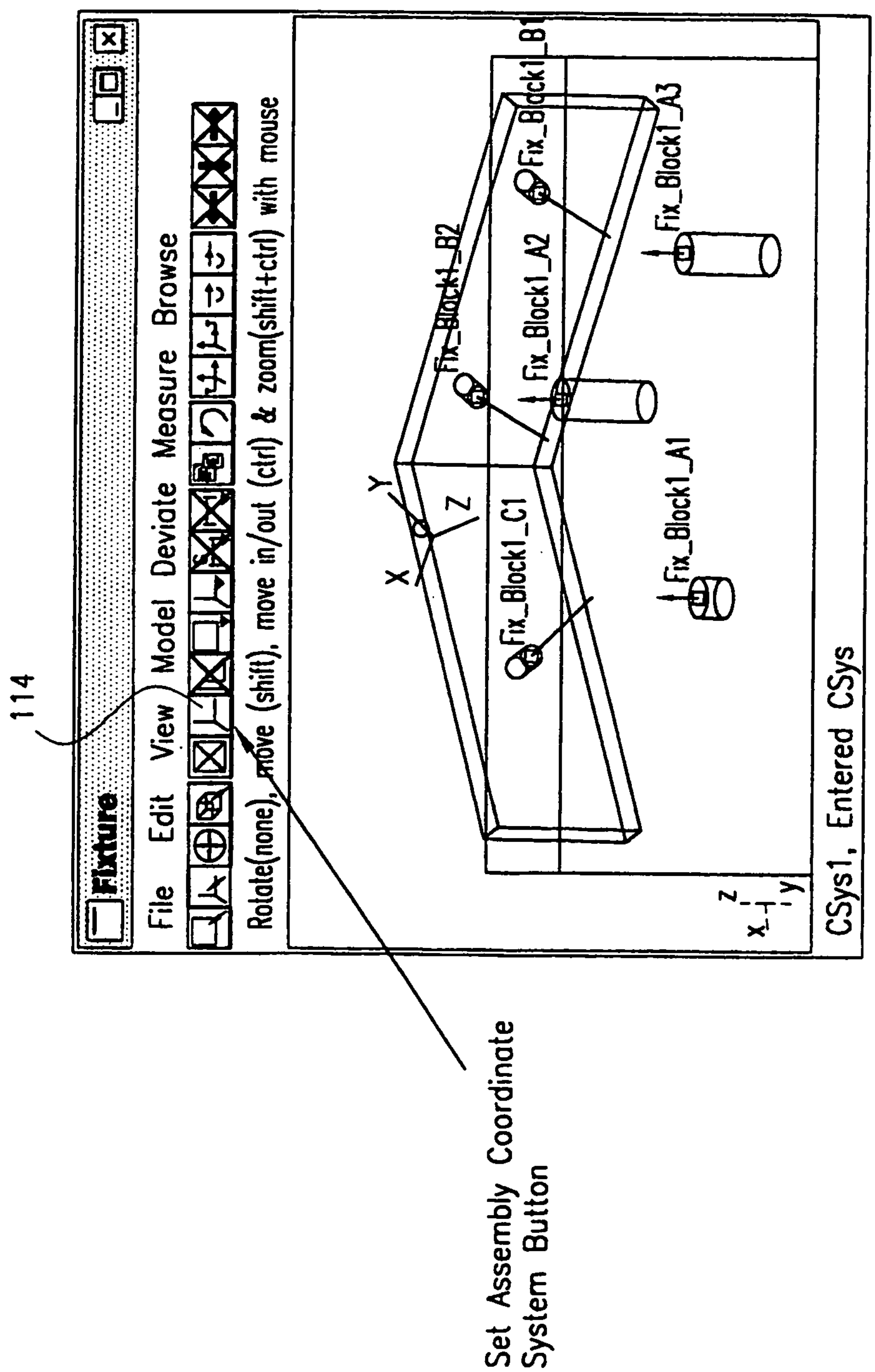

114
Fixture
File Edit View Model Deviate Measure Browse
Rotate(none), move (shift), move in/out (ctrl) & zoom(shift+ctrl) with mouse
Fix_Block1_B1
Fix_Block1_A3
Fix_Block1_B2
Fix_Block1_A2
Fix_Block1_A1
Fix_Block1_C1
X
Y
Z
CSys1, Entered CSys
Set Assembly Coordinate System Button

FIG. 10

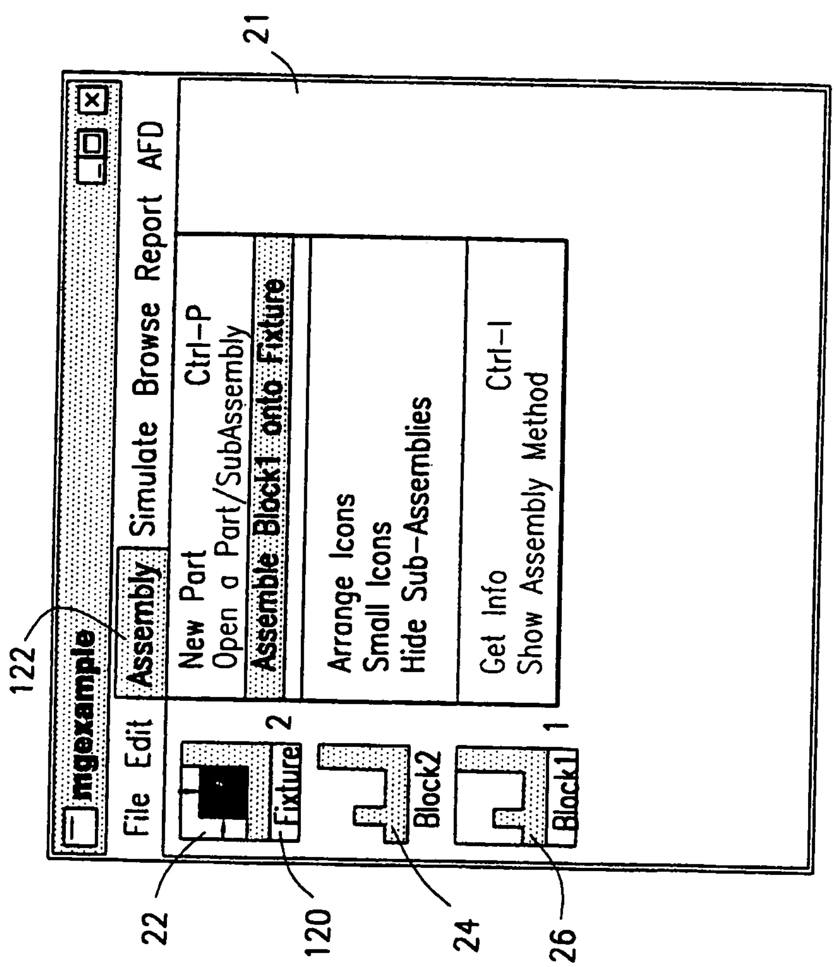

mgexample
File Edit Assembly Simulate Browse Report AFD
New Part Ctrl-P
Open a Part/SubAssembly
Assemble Block1 onto Fixture
Arrange Icons
Small Icons
Hide Sub-Assemblies
Get Info Ctrl-I
Show Assembly Method
Fixture
2
Block2
Block1
1
122
21
22
120
24
26

FIG. 11

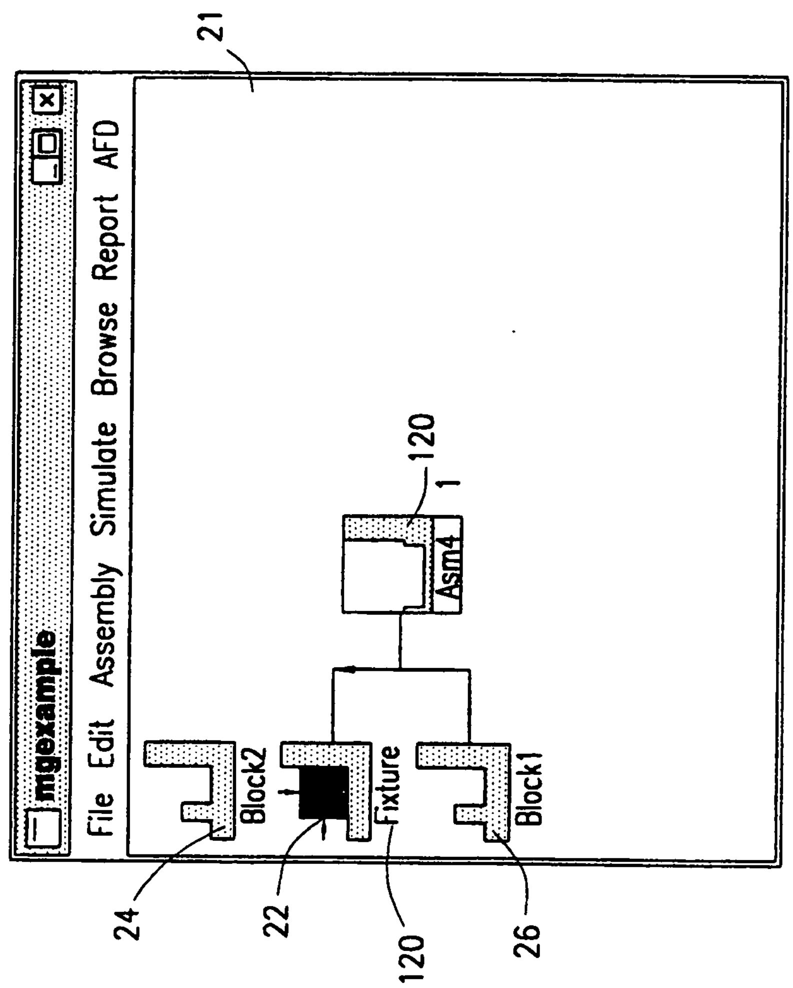
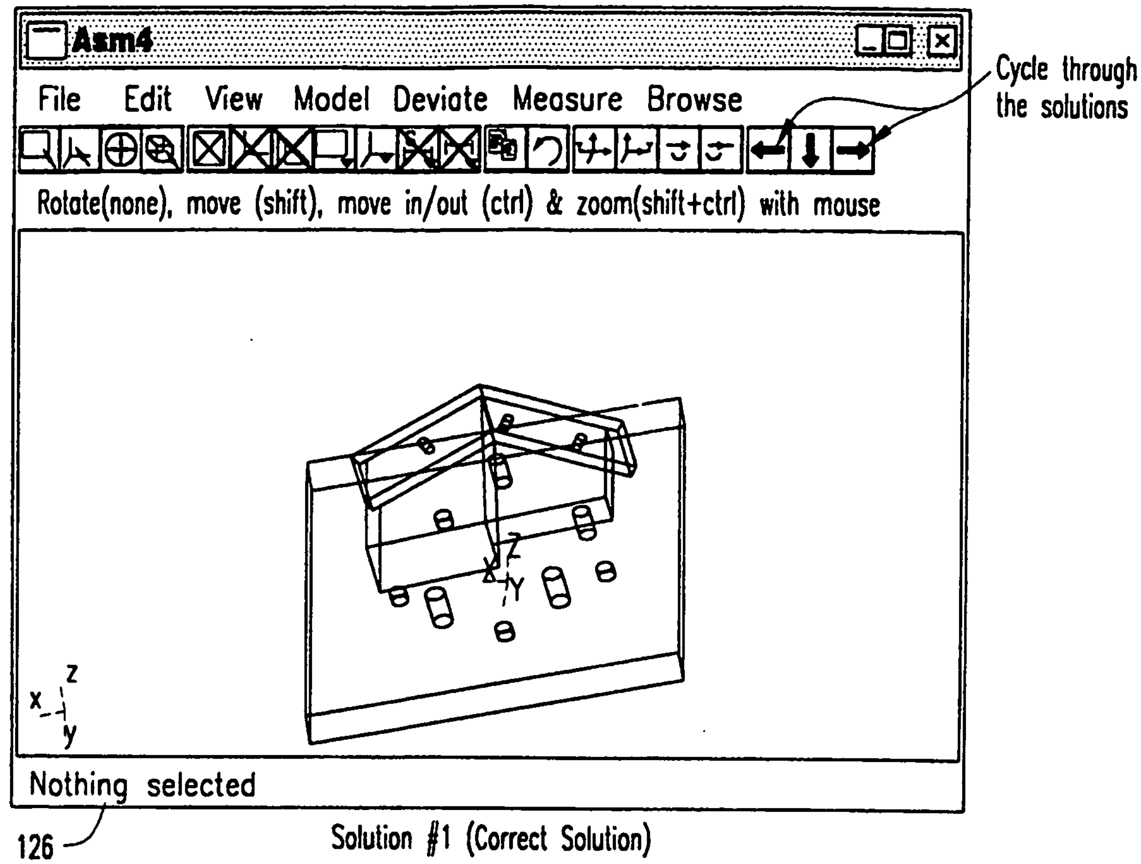
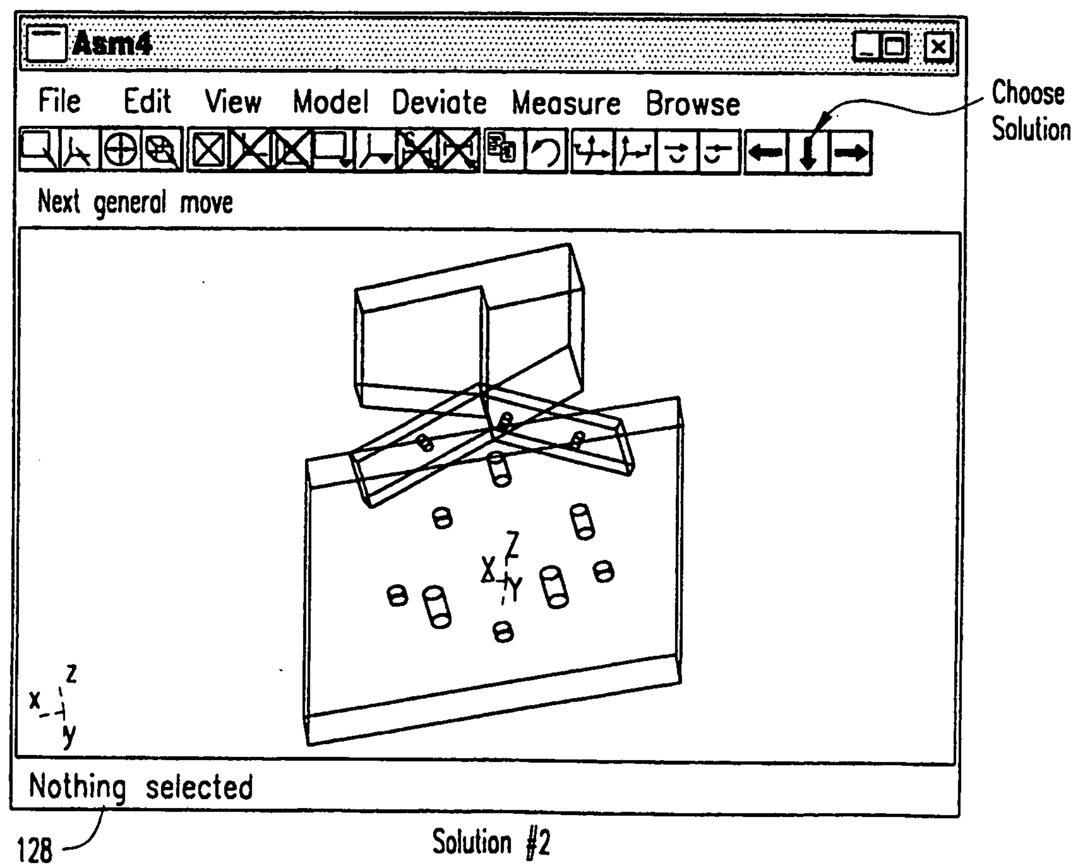

mgexample
File Edit Assembly Simulate Browse Report AFD
Block2
Fixture
Block1
Asm4
1
120
21
24
22
120
26

FIG. 12



Solution #1 (Correct Solution)

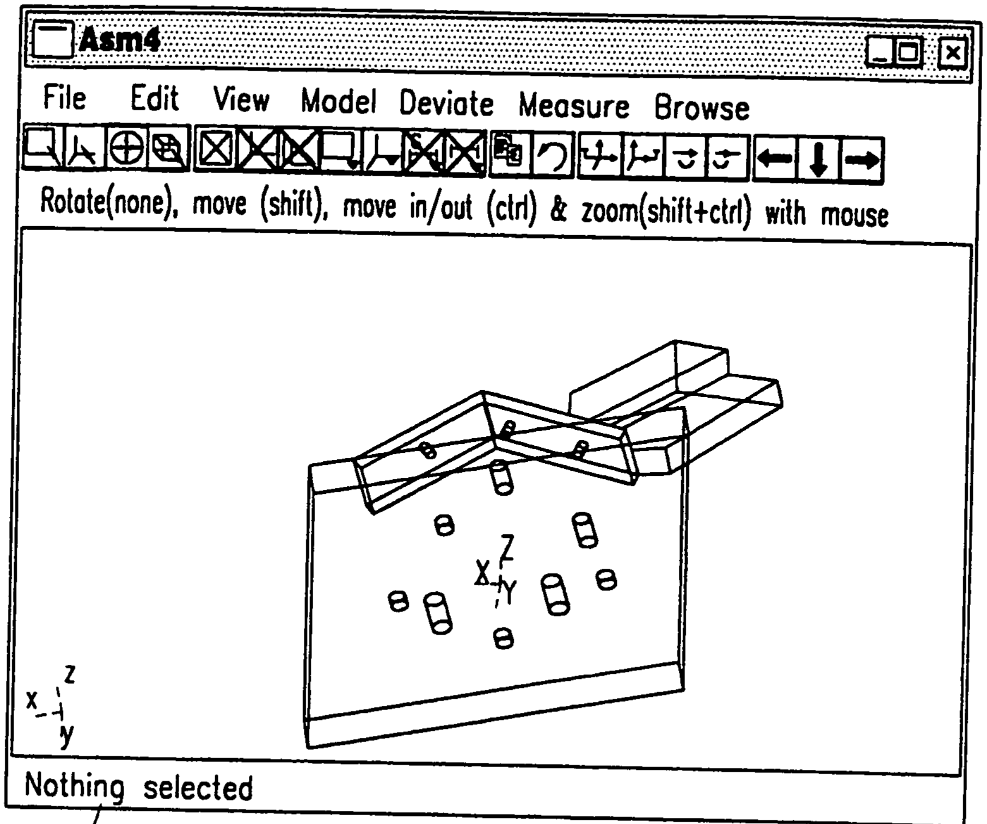
(a)



Solution #2

(b)

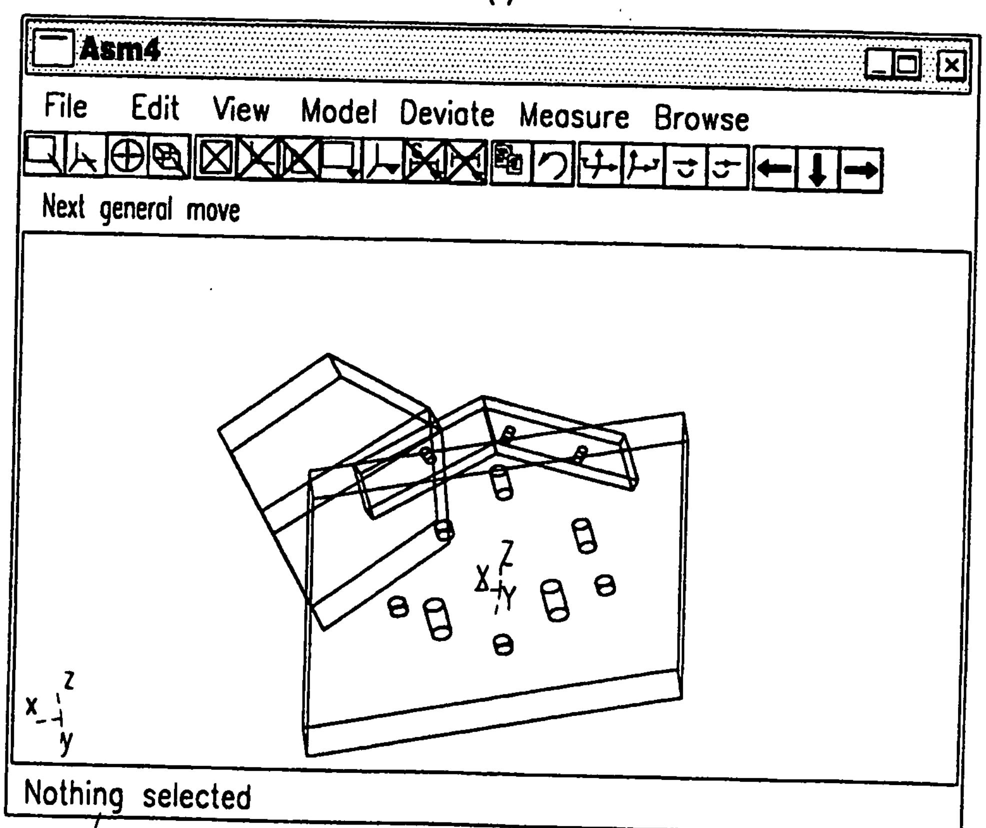
FIG. 13



130

Solution #3

(c)



132

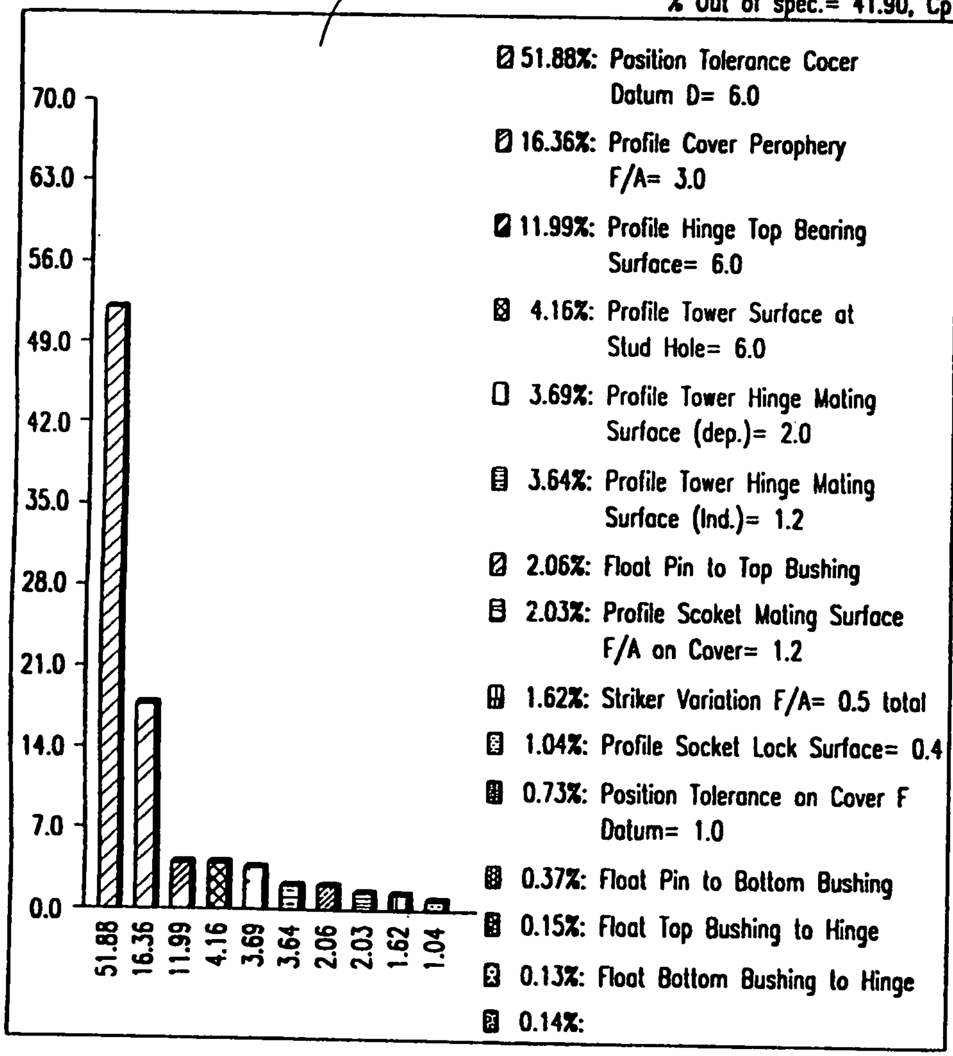
Solution #4

(d)

FIG. 13

Gap-Tire to Cover in F/A Direction at Point AA

Specification:LSL= 0.00, Nominal= -0.00, USL= N/A
Control Limits: LCL= -3.60, Mean= 0.26, UCL= 3.59
% Out of spec.= 41.90, Cp= N/A, Cpk= 0.07, Mean Shift= 0.26



150

Distr.	Type:	Normal	Sample Size:		5000
90.0% Conf. Int. in Est.				Sample Est	(99.73%)
Mean:	0.2294	0.2851	Min.:	-4.3326	-3.3376
Std:	1.1789	1.2186	Max.:	4.2922	3.8522
Cp:	N/A	N/A	%<LSL:	41.9000	41.5002
Cpk:	0.0704	0.0727	%>USL:	N/A	N/A
%OutS.:	41.2600	48.5992	%OutS.:	41.9000	41.5002

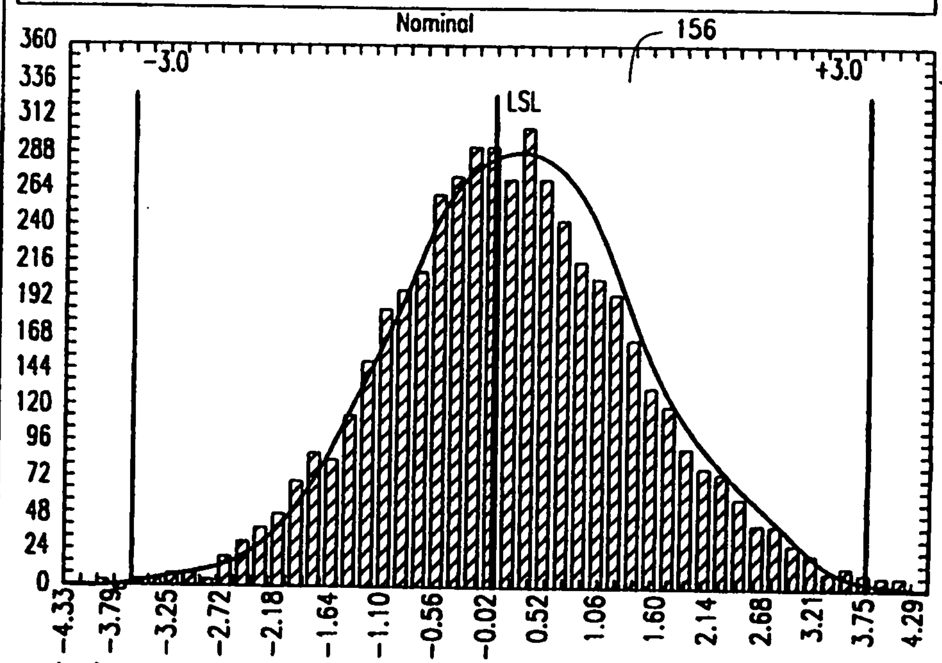


FIG. 14

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Gap-Cover Periphery to Tower Face in F/A Direction at Point Cover Top

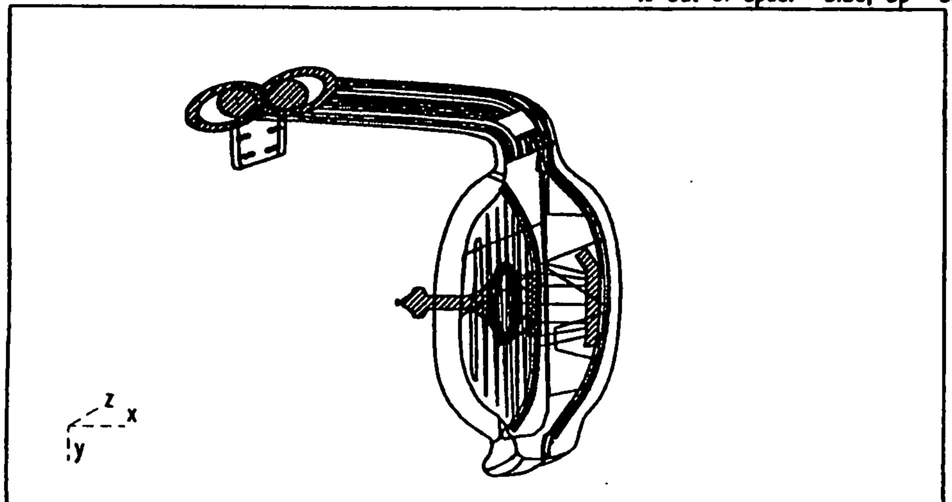
Specification:LSL= -94.16, Nominal= -90.16, USL= -86.16

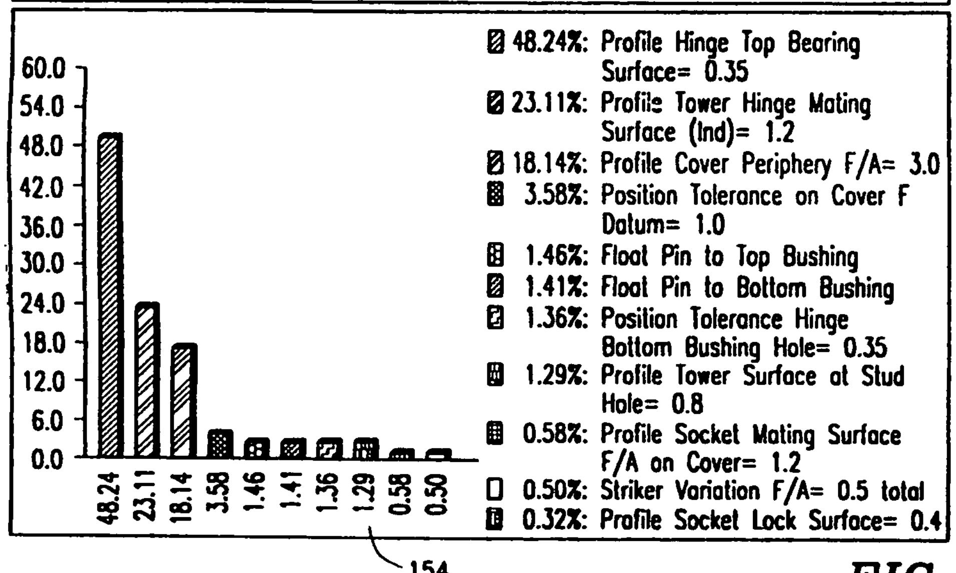
Control Limits: LCL= -94.83, Mean= -90.31, UCL= -85.79

% Out of spec.= 0.86, Cp= 0.89, Cpk= -0.85, Mean Shift= -0.15

152

Distr.	Type:	Normal	Sample Size:		5000
90.0%	Conf. Int. in Est.			Sample Est (99.73%)	
Mean:	-90.3473	-90.2773	Min.:	-94.9165	-94.8299
Std:	1.4815	1.5313	Max.:	-84.8848	-85.7947
Cp:	0.8707	0.9000	%<LSL:	0.4400	0.5264
Cpk:	0.8385	0.8667	%>USL:	0.4200	0.2938
%OutS.:	0.7800	1.2119	%OutS.:	0.8600	0.8202





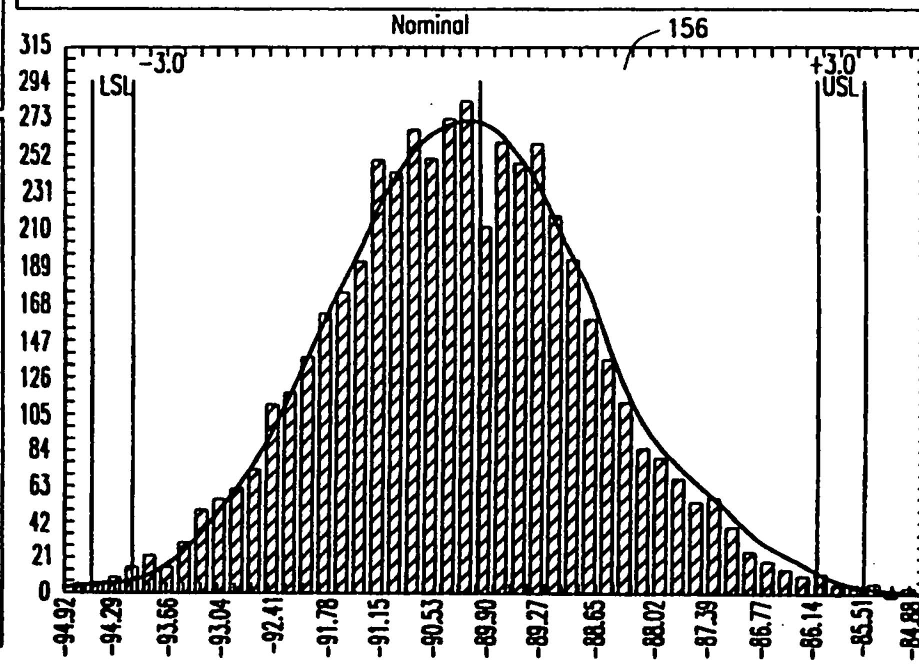


FIG. 15

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/02258

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G05B19/4097 G05B19/418

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	US 5 949 693 A (TANDLER WILLIAM) 7 September 1999 (1999-09-07) column 8, line 3 -column 49, line 14; figures 1-26	1-29
X	US 4 918 627 A (GARCIA CHRISTOPHER J ET AL) 17 April 1990 (1990-04-17) column 4, line 20 -column 68, line 60; figures 1-16	14-33
X	EP 0 452 944 A (HITACHI LTD) 23 October 1991 (1991-10-23) page 6, line 15 -page 18, line 15; figures 1-29	1-21

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
30 May 2000	07/06/2000

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97 01802 A (BOEING CO ;ATKINSON ROBERT E (US); MILLER TERESA S (US); SCHOLZ FR) 16 January 1997 (1997-01-16) page 10, line 10 -page 30, line 11; figures 1-17	22,30,33
A	US 5 208 763 A (HONG JIAWEI ET AL) 4 May 1993 (1993-05-04) abstract	1-37
A	US 5 586 052 A (IANNUZZI MARK P ET AL) 17 December 1996 (1996-12-17) abstract	1-37
A	US 5 465 221 A (MERAT FRANCIS L ET AL) 7 November 1995 (1995-11-07) abstract	1-37
A	VIJAY SRINIVASAN ET AL: "ON INTERPRETING STATISTICAL TOLERANCING" , MANUFACTURING REVIEW,US,AMERICAN SOCIETY OF MECHANICAL ENGINEERS, NEW YORK, VOL. 7, NR. 4, PAGE(S) 304-311 XP000482443 ISSN: 0896-1611	22-37
A	WU C -C ET AL: "Component tolerance design for minimum quality loss and manufacturing cost" , COMPUTERS IN INDUSTRY,NL,ELSEVIER SCIENCE PUBLISHERS. AMSTERDAM, VOL. 35, NR. 3, PAGE(S) 223-232 XP004123780 ISSN: 0166-3615	22-37

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 00/02258

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 5949693	A	07-09-1999	NONE			
US 4918627	A	17-04-1990	AU	598284	B	21-06-1990
			AU	7657687	A	11-02-1988
			CA	1284383	A	21-05-1991
			CH	678761	A	31-10-1991
			DE	3725347	A	18-02-1988
			FR	2617306	A	30-12-1988
			GB	2194367	A,B	02-03-1988
			GB	2230363	A,B	17-10-1990
			GB	2230364	A,B	17-10-1990
EP 0452944	A	23-10-1991	JP	2786306	B	13-08-1998
			JP	4002481	A	07-01-1992
			JP	4002432	A	07-01-1992
WO 9701802	A	16-01-1997	AU	6674396	A	30-01-1997
			CA	2222324	A	16-01-1997
			CN	1194041	A	23-09-1998
			EP	0835480	A	15-04-1998
			US	5956251	A	21-09-1999
US 5208763	A	04-05-1993	WO	9205399	A	02-04-1992
US 5586052	A	17-12-1996	NONE			
US 5465221	A	07-11-1995	NONE			

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